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A review of equalisation techniques for analogue television signals

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A REVIEW OF EQUALISATION TECHNIQUES FOR ANALOGUE TELEVISION SIGNALS

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Summary

Automatic equalisers are considered, in relation to their suitability for inclusion in the existing national television network.

Both time-domain and frequency-domain equalisers are discussed and it is concluded that, whilst the great majority of links should continue to be equalised individually using fixed, passive equalisers, improved average overall performance would most probably result if automatic frequency-domain equalisers were added at suitable points in the network in order to correct both the residual distortions of the links and their variations with time.

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A REVIEW OF EQUALISATION TECHNIQUES FOR ANALOGUE TELEVISION SIGNALS

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A REVIEW OF EQUALISATION TECHNIQUES FOR ANALOGUE TELEVISION SIGNALS

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1. Introduction

When transmitted over a link, a television signal is impaired by linear distortions (caused by non-uniformities in the amplitude and group-delay responses of the link as functions of frequency), by non-linear distortions (caused by non-linear transfer characteristics), and by the introduction of thermal noise or other unwanted signals. Provided the signal level is maintained between specified limits, the non-linear distortion and the level of noise introduced by a well-engineered link is small. Linear distortions, however, are common and it is customary to associate an equaliser with every link, not only to make its amplitude and group-delay characteristics as a function frequency sufficiently uniform but also to maintain the specified signal levels at various points. Most links used by the BBC are owned by the Post Office. Some of them are equalised entirely by the Post Office whilst others are equalised entirely by the BBC and, for the remainder, some equalisation is performed by both organisations.

At the present time the great majority of such equalisation is carried out manually before the link is used for a programme, but it is now technically feasible to perform the operation automatically and, within limits, to optimise the equalisation continuously throughout the programme. In addition to a possible saving in manpower, automatic equalisers therefore offer two potential advantages with regard to programme quality:

(i) impairments caused by changes in the linear propagation characteristics of each link would be corrected continuously

and *(ii)* automatic equalisers could provide overall corection for the cumulative linear distortions which occur in a long cascade of individually-equalised links. It is tempting to suggest that some links could remain completely unequalised, relying upon an automatic equaliser later in the chain to provide overall correction but, as will be discussed later, this is not considered desirable.

If, in the future, television signals are transmitted over digital links in p.c.m. form, it is likely that the associated automatic equalisers will not require special test signals. For analogue waveforms, however, such signals are required which, for the equaliser to optimise continuously, must be transmitted with the programme signal.

The test signals must therefore be of a kind which do not affect the programme and the only feasible part of the television waveform in which they could be located is one or more lines of the field-blanking interval. Test signals for quality control (both manual and automatic) which are currently added on some of those lines have become so firmly established both nationally and internationally that it would not be practicable to change them. Furthermore, since other uses have been suggested for the remaining lines,[1,2] it would not be feasible to insert additional test signals that may be more suited to particular forms of automatic equaliser. Thus one of the main considerations which governs the choice of a particular type of automatic equaliser is its ability to use the existing test signals.

Because the form of the test signals has such a great bearing on the choice of automatic equaliser, it is convenient first to summarise current practices and then to consider the introduction of automatic equalisers within that framework. Equalisers are linear networks which correct only linear distortions but due consideration is given in this report to the effect on their performance of non-linear distortion and thermal noise.

2. Review of current practice

2.1 Television links

The BBC television network[3] comprises both long- and short-distance links. In most cases, the Post Office links are permanently connected for the exclusive use of the BBC but some are made available temporarily for particular programme requirements.

To simplify the specification of their performance limits, links are classified into three groups:[4]

(i) Those having a route length of between 40 km and, say, 200 km; these are termed "main links".

(ii) Those having a route length less than 40 km but nevertheless include repeaters; these are termed "major local links".

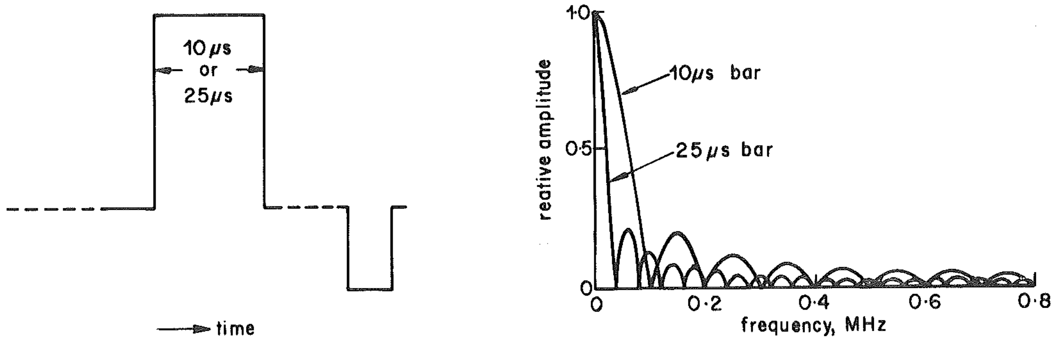
and *(iii)* Those having a route length less than 40 km and do not include repeaters; these are termed "minor local links".

Performance limits, in terms of the distortions caused to certain special test signals (see Section 2.2) have been defined for links in the above groups[4,5] and also for international links up to 2,500 km in length[5,6].

2.2 Test signals

2.2.1 General

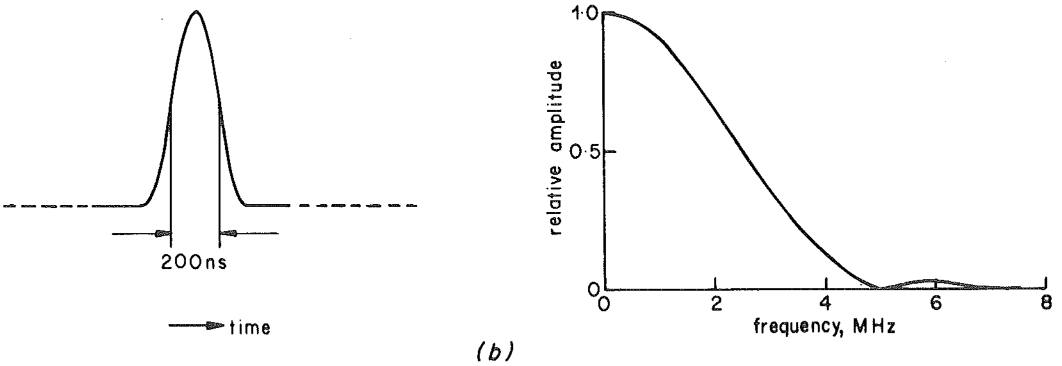
The performance characteristics of a link could, in principle, be expressed as functions of either frequency or time but, since the link is to carry a signal whose waveshape is improtant, it is considered that the performance is better expressed in terms of a time-response rather than in terms of response/frequency characteristics. Thus test signals such as multiburst, or pilot-tones at frequencies between the picture signal line harmonics, are not regarded as suitable test signals, and are not considered here. Instead, the performance of a link is specified in terms of the waveform distortion of particular test signals. Experience in the UK has shown that it is possible to choose for these purposes a comparatively small number of test signals whose spectral energy is concentrated around certain important regions of the transmission bandwidth.[6,7,8,9] The most important waveforms in general use are a rectangular bar, a sine-squared pulse, and rectangular and sine-squared composite pulses; these, with the exception of the rectangular composite pulse are illustrated in Fig. 1 and are described more fully below.



(a)

(i) *Time function*

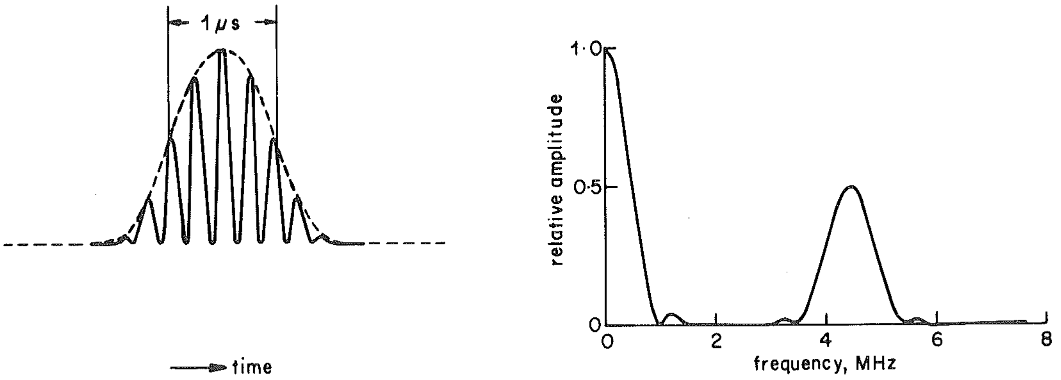
(ii) *Spectral envelope*



(b)

(i) *Time function*

(ii) *Spectral envelope*



(c)

(i) *Time function*

(ii) *Spectral envelope*

Fig. 1 - Waveforms and spectral envelopes of test signals

(a) 10 μs and 25 μs bars *(b) 2T Sine-squared pulse* *(c) 10T Composite pulse*

Rectangular Bar (Fig. 1(a))

This is a rectangular pulse, occurring during one or more lines of each field, and extending from black level to white level. Its duration is either 25 μs or 10 μs, depending respectively upon whether it is transmitted on every active picture line for acceptable tests and manual equalisation before the programme (see Section 2.2.2), or during field blanking intervals for quality-checking purposes (see Section 2.2.3). Because its spectral energy occurs mainly at low frequencies, its shape provides a sensitive indication of distortions occurring at frequencies less than about 500 kHz. The voltage at the central region of the bar is taken to correspond to "white level" in the television waveform.

To investigate distortion which may occur at frequencies below line frequency, a 50 Hz square-wave test signal is used in which half the lines of each field are at white level and the remaining half are at black level.

Sine-Squared Pulse (Fig. 1(b))

This is a pulse of sine-squared shape, occurring during one or more lines of each field, and extending from black level to white level with a half-amplitude duration (designated "2T") equal to 200 ns. Because its spectral energy extends to 5 MHz, the shape (notably the pulse height and the overshoots near the base) provides a sensitive indication of distortions in the middle range of frequencies. Since the pulse has negligible spectral energy at frequencies above 5 MHz, it is unaffected by distortions which occur outside the transmission bandwidth.

Composite Pulse (Fig. 1(c)) and Bar

All current coding systems for broadcast colour-television signals involve a luminance component occupying effectively the whole of the baseband, and chrominance components which modulate a sub-carrier located near the upper end of the baseband. Since the relationship between these two sets of components is extremely important, test signals for a colour television channel comprise both the chrominance test signals and a luminance reference component. Two such composite test signals are used. Each consists of chrominance sub-carrier, modulated by a waveform that serves also as the luminance reference component. One composite test signal is based upon a half-amplitude rectangular bar of duration either 25μs or 20μs depending respectively upon whether it is transmitted on every active picture line for acceptance tests and manual equalisation (see Section 2.2.2), or during field-blanking intervals for quality-checking purposes (see Section 2.2.3). The other composite test signal is based upon a half-amplitude 10T sine-squared pulse. The spectral energy of these test signals is mainly confined to low frequencies and to frequencies around that of the colour sub-carrier; the waveform and the spectral energy distribution of the 10T composite test signal are shown in Fig. 1(c). The envelope shape* of both types of composite pulse provides a very sensitive and diagnostic indication of luminance-chrominance gain and delay inequalities[9] although the clarity of this indication is impaired if chrominance-luminance crosstalk is present. In order to indicate the presence or absence of the latter effect the duration of the chrominance component of the composite bar signal is, in some test signals, made shorter than that of the associated luminance component[9].

2.2.2 Test signals for manual equalisation

Manual equalisation is performed prior to a programme using the 50 Hz square-wave test signal or, on every picture line, the 25 μs bar, 2T pulse, and the 10T and 25 μs composite pulse-and-bar test waveforms. The general procedure is outlined in Section 2.4.

2.2.3 Insertion test signals

A test signal has been specified nationally,[10] and recommended internationally,[11] which is transmitted during two lines of each field-blanking interval. The need for an internationally-agreed signal is fully recognised and the most suitable form for it to take is being studied.[12,13] The signal in current use in the UK, known as the insertion test signal (I.T.S.) comprises the 10 μs bar, 2T pulse, and the 10T and 20 μs composite pulse-and-bar signals (together with further test signals that enable measurements of non-linearity to be made); it is transmitted during lines 19, 20, 332 and 333 of each picture.[10] Clearly, such signals cannot be used to correct linear distortions at frequencies less than line frequency, nor can they be used in their present form for the '3 dB overload' tests, which are used to assess certain non-linear distortions, but they have been shown to give good indications of luminance gain and K-rating, and luminance-chrominance gain and delay inequalities, in addition to signal-to-noise ratio and four types of non-linear distortion[14]. They are also being considered[15] or are in use[16,17] for automatic monitoring at transmitting stations.

2.3 Performance limits

Performance limits that both national and international links should satisfy before they are used for programme signals have been defined 3,4,5,6. Links owned by the Post Office are not normally accepted if their signal-to-noise ratios or non-linear distortions fall outside those limits, but links which exhibit only linear distortions are usually accepted (and equalised) by the broadcasting authorities. For some links only residual equalisation is required but, for others, the BBC provides up to 40 dB correction for the amplitude/frequency response and/or ± 195 ns correction for luminance-chrominance delay inequality.

2.4 Manual equalisation

Manual equalisation is performed using the test signals described in Section 2.2. Each signal is used individually in correcting the kinds of distortion to which it is particularly sensitive; one adjustment affects the others to a certain extent but, particularly with a skilled operator, the test signals are such that the process is rapidly convergent.

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*Fig. 1(c) shows the waveform of the pulse on one field. Because of the relationship between the line frequency and the colour sub-carrier frequency in System I transmissions, the phase of the colour sub-carrier within the envelope is different for each of the seven subsequent fields and thus, when viewed on an oscilloscope, the individual cycles of colour sub-carrier cannot readily be distinguished and the envelope appears to be 'full' of sub-carrier.

Experience has shown that very precise amplitude/frequency adjustments are sometimes required at frequencies up to about 1 MHz; an equaliser is used which comprises fourteen sections, each of which can provide a small 'bump' or 'hollow' in the amplitude/frequency response over a fairly narrow range of frequencies.[18]

The loss, as a function of frequency, for the 9·5 mm diameter air-spaced co-axial cable in use for typical short links is given approximately by:

$$L = 2{\cdot}34\ \sqrt{f}\ \text{dB per km}$$

where f is the frequency in MHz. These characteristics, for 2 km and 8 km links, are shown in Fig. 2. Special networks have been devised[19] whose loss varies in a complementary manner, and equalisers using four such networks have been designed which provide amplitude/frequency correction for links for this type up to 8 km in length[20].

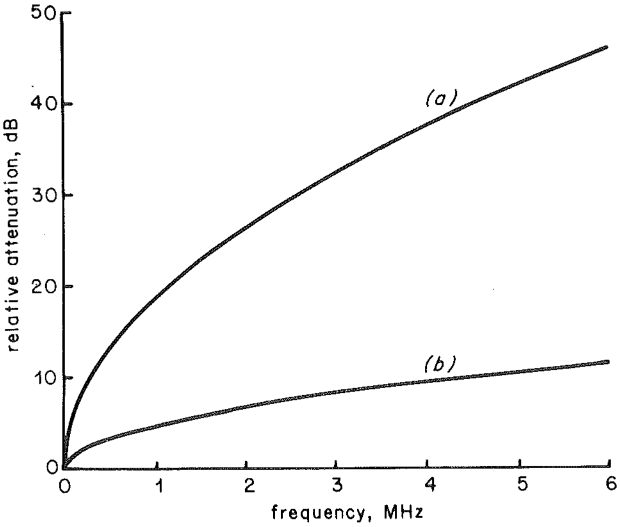

Fig. 2 - The attenuation characteristic of 9·5 mm dia. air-spaced co-axial cable links
(a) 8km path length (b) 2km path length

Surprisingly, group-delay/frequency correction is usually required to correct only luminance-chrominance timing errors and, for that purpose, an equaliser comprising ten cascaded all-pass sections, which can provide up to ±195 ns delay (in 15 ns steps), is used.[21]

3. Automatic equalisation

3.1 General

Automatic equalisers for analogue television signals require a test signal which must be transmitted either prior to the programme (the equaliser operates upon it at that time and then maintains its settings throughout the programme) or during the programme (the equaliser optimises its settings continuously). The latter mode of operation is clearly preferable since the equaliser may then correct for changes in the overall propagation characteristics of the entire chain, including those caused by deliberate switching operations during the programme. It is not feasible, however, to include a suitable test signal with the programme other than during one or two lines within each field-blanking inverval and it is not practicable for an automatic equaliser to correct distortions which occur at frequencies less than two or three times the line frequency, owing to the low energy in such test signals at these frequencies.

It is generally considered desirable to equalise the great majority of links individually in order to maintain reasonable signal quality, and to minimise impairments caused by either noise or non-linear distortion, at all junction points in a programme chain. It would be feasible to equip each link with an automatic equaliser providing approximate equalisation by reference to special test signals transmitted before the programme and, at the end of the series of links, to provide an additional automatic equaliser optimising the overall characteristics continuously throughout the programme. The use of an automatic equaliser on each individual link is not recommended, however, since passive equalisers have been found to be amongst the most reliable parts of the broadcast chain, and the minor advantage gained by replacing them by their automatic counterparts would probably lead to reduced overall reliability. An automatic equaliser that corrects for the residual distortions of a long series of links would, however, have much greater advantage. A recent assessment[22] has shown for example, that 8% of the sample measurements made over a nine-month period on the BBC-2 distribution chains were out of tolerance, despite normal routine manual readjustments to the equalisers of the individual links forming the chains. Discussion has therefore been confined to automatic equalisers suitable for overall correction of a series of links.

Automatic equalisers may either:

(i) Comprise sections whose amplitude/frequency and group-delay/frequency responses may be varied in a prescribed manner and which are adjusted automatically according to particular features of the separate components of the test signal, using algorithms similar to the procedures used in present manual methods. This form is termed a 'frequency-domain' equaliser.

or

(ii) Adjust the overall time-function response of the link plus equaliser so as to render the shape of a single incoming distorted test signal sufficiently similar to that of an undistorted reference signal. This may be achieved by adding contributions that are either time-derivatives or 'pre-echoes' and 'post-echoes' of the input signal. This form is termed a 'time-domain equaliser'.

It is considered that non-linear distortions are likely to impair the operation of a time-domain equaliser more than a frequency-domain equaliser because, although the equaliser will add contributions that correct the shape of the test signal, the added corrections will not generally apply for the programme waveform. A frequency-domain equaliser, on the other hand, operates on features of the test signal that tend to be less affected by non-linear distortion.*

3.2 Automatic frequency-domain equalisers

An automatic equaliser has been described[23] which operates by adding to the input signal suitable contributions which have been derived by passing the input signal through circuits having prescribed amplitude/frequency and group-delay/frequency characteristics. Three contributions are obtained from simple networks having 'half-loss' frequencies at about 30 kHz, 100 kHz and 300 kHz. Four further contributions are taken from the taps of a four-section transversal filter whose outputs are arranged in symmetrical and skew-symmetrical echo-pairs such that two contributions affect the overall transfer characteristics in the middle range of frequencies and the other two are effective over the frequency band occupied by the chrominance signals. A variable-gain amplifier is included to enable the correct overall signal level to be obtained at the equaliser output.

The equaliser adapts itself continuously throughout the programme with reference to the current I.T.S. (see Section 2.2.3). Measurements of particular features of the test signal are made using peak-measurement techniques[16] and the results are used to develop control voltages that determine the magnitude of the appropriate contributions. The low-frequency contributions are determined by measurements on the 10 μs bar, the middle-frequency contributions by measurements at the peak and at the base of the 2T sine-squared pulse, and the chrominance-band contributions by measurements on the 10T composite pulse and the 20 μs composite bar. The output signal level is determined by measurements at the mid-point of the 10 μs bar. All these measurements are made on the output signal, thus achieving closed-loop operation, and all control voltages are held constant if the I.T.S. is temporarily removed.

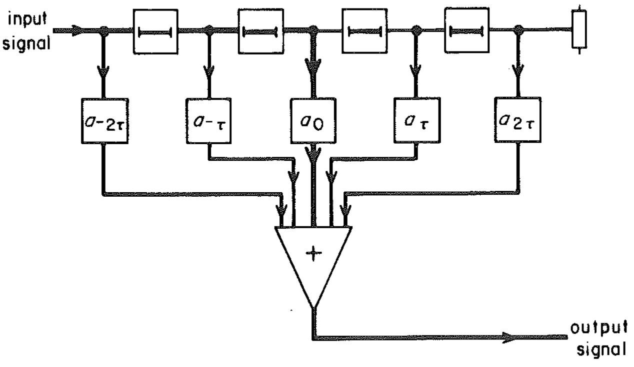

Fig. 3 - A time-domain equaliser

The unit is very compact and, in its present form, is intended to equalise only the residual distortions at the end of a long cascade of individually-equalised links. In that application it can provide at least an eight-fold reduction of linear distortions and its performance is not impaired by normally-acceptable amounts of non-linear distortion or thermal noise.

3.3 Automatic time-domain equalisers

3.3.1 The use of transversal equalisers

Two distinct methods of time-domain equalisation have been described in which the input signal is corrected by adding contributions that are either pre-echoes and post-echoes[24] or time-derivatives[25] of the input. The former method has recently received much attention in the technical press, both automated[26,27,28,29] and otherwise[30,31,32,33] and, because it is readily automated, is the only method to be considered here. The method uses a transversal equaliser, as shown in Fig. 3, in which the input signal is applied to a tapped delay line and the output signals from the taps are each controlled by an attenuator and summed to produce the complete output signal. The form of the attenuators, shown symbolically in Fig. 4, is such that their transfer function (shown as a_r in Fig. 3) may be any real number between $+g$ and $-g$. where g is the gain of an amplifier associated with each attenuator. It is usual to provide an even number of delay sections (and hence an odd number of taps) and for the output from the central tap to constitute the main signal path and for the outputs from the other taps to constitute the required corrections.

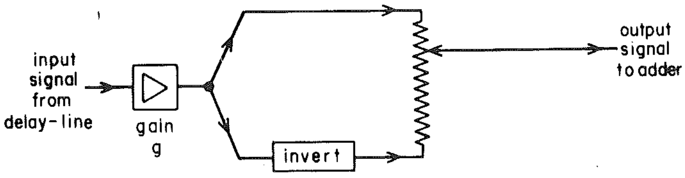

Fig. 4 - Symbolic representation of attenuators, a_r

It may be shown that, for complete equalisation, the delays between taps must all be equal and must not exceed the Nyquist interval (equal to the reciprocal of twice the highest frequency to be equalised). For practical conditions, some 10% less delay than that has been recommended.[28] Thus a typical value for System I television signals would be 80 ns.

The number of taps is inversely proportional to the lowest frequency to be equalised. Twenty sections have been proposed for a television signal[28] but, if a fine degree of equalisation is required at frequencies below about 500 kHz (see Section 2.4), that number would be insufficient. Recursive arrangements enable fewer sections to be used but the degree of equalisation is restricted and special constraints are necessary in order to avoid instability.[29] Furthermore, the correction algorithm for an automated version is more complicated.

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*Some of the distortion products (in terms of frequency) will occur outside the transmission band.

3.3.2 Automatic adjustment of transversal equalisers

In order to automate an echo-sum time-domain equaliser, the test signal (see Section 2) is gated out and sampled at intervals equal to the delay per section. It is customary to perform this sampling on the output signal so that the equaliser operates under closed-loop conditions. The magnitude and polarity of each sample is compared to a reference voltage equal to that of the corresponding sample of an undistorted test signal and, at this stage, either of two strategies may be adopted.

For one strategy (known as the zero-forcing method), the magnitudes and the polarities of the outputs from the comparators are fed to a logic unit which performs the appropriate calculation and subsequently adjusts all the attenuators (a_r) simultaneously such that every sample is made equal to its associated reference voltage. This, however, is not necessarily the best result because, although all the waveform errors are corrected for the duration of the test waveform, cumulative residual errors are introduced before and after this interval which may make the overall result unacceptable. Furthermore, the logic unit must perform a completely new calculation whenever a change occurs to the incoming signal. This strategy is therefore considered to be unsuitable for an equaliser which is to correct continuously for small changes in the propagation characteristics of a long cascade of links.

For the second strategy, the settings of the attenuators are adjusted according to an optimisation routine. Such an arrangement is shown in Fig. 5 in which, after each test signal, an incremental change is made to each attenuator according to an algorithm based on the state of its associated comparator. These settings are maintained until the arrival of the next test signal, after which they are up-dated as required. Lucky has described algorithms by which either the mean-squared error or the mean error may be minimised[26]. The first algorithm ensures convergence regardless of the degree of linear distortion initially present on the signal, but it requires sophisticated circuitry involving cross-correlation between the error signal and the contributions from all the taps. On the other hand, the second, which minimises the mean error, simply requires the contribution from each individual attenuator to be reduced if the sample presented to its associated comparator is larger than its reference voltage (and vice-versa). This simple algorithm ensures convergence only when the modulus of the algebraic sum of all the errors is less than the peak value of the test signal, but Arnon has shown[28] that it gives good results for a television signal, and the restriction on convergence is unimportant provided the equaliser has to deal only with the residual distortions of a nearly-equalised television channel.

3.3.3 Computer simulation of an automatic time-domain equaliser

Four important questions arise when considering the the application of such an equaliser to the existing UK television network, namely:

(i) How well-suited is it to the current test signals?

(ii) How closely must the distorted test signal be made to resemble a given undistorted reference signal?

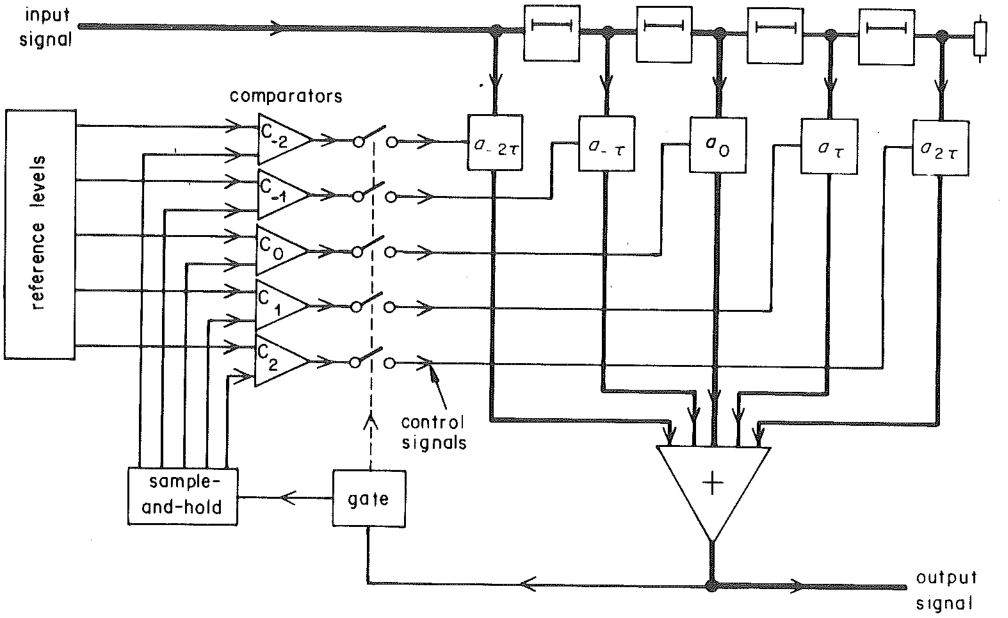


Fig. 5 - An automatic time-domain equaliser

(iii) How rapidly does the optimisation converge to the required result?

and

(iv) What timing accuracy of sampling is required?

These aspects have been studied by computer simulation as follows:

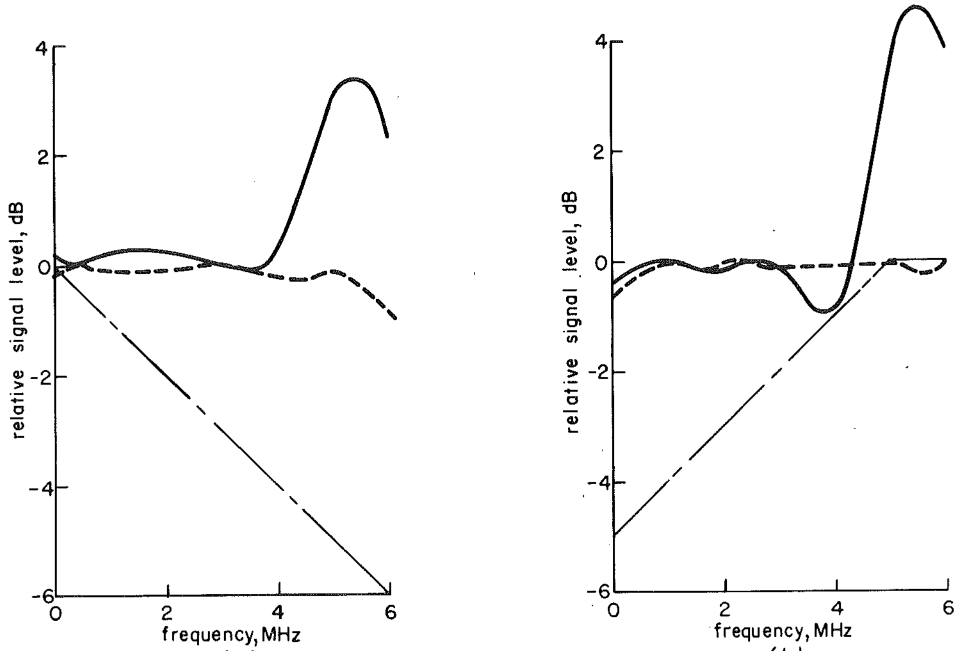
To study the first three questions, the operation of an equaliser of the type shown in Fig. 5 using 10 sections, each of 90 ns delay, was simulated. The peak value of the undistorted test pulse was taken as unity and the contribution (a_r) from each attenuator was allowed to vary in relative gain steps of ± 0·01. Initially, the contribution a_o was set at unity and all other contributions were set to zero. If the r th sample exceeded the r th reference voltage by more than 0·01, the contribution from the r th attenuator was decreased by one step, and vice-versa. This performed on each contribution once, constituted one optimisation loop. This corresponds to a sampling accuracy of 1% which, when the effect of noise is considered, is regarded as the highest practicable sampling accuracy.

The test signal comprised a sine-squared pulse of half-amplitude duration 180 ns. This corresponds to a 2T pulse in a 5·555 MHz system and, although it is different from the 200 ns standard adopted in the UK (see Section 2.2.1), the difference is small and could readily be allowed for if necessary. The reference signal was obtained by bandwidth-limiting the sine-squared pulse to 5·555 MHz by a perfect filter; the distorted test pulse was obtained by passing this bandwidth-limited pulse through a further network (simulating the transmission channel) whose transfer characteristics could be chosen.

Fig. 6 shows the resulting overall response/frequency characteristics of the channel plus equaliser when transfer characteristics comprising a 1 dB/MHz fall with increasing frequency and 1 dB/MHz fall with decreasing frequency (both with uniform delay characteristics) were chosen for the transmission channel. It is evident that the equaliser performance is quite inadequate at frequencies above about 4 MHz. This is because less than 1% of the total energy of the sine-squared pulse occurs at frequencies above 4 MHz (see Fig. 1(b)) and thus an impracticably high order of sampling accuracy is required. Thus the 2T pulse alone would not be an adequate test signal.

To confirm that point, corresponding results were obtained using a (sin x)/x-type reference signal derived by bandwidth-restricting a 90 ns rectangular pulse to 5·555 MHz. The results, also given in Fig. 6 show that it provides good equalisation over the majority of the frequency range. No single element of the current I.T.S. has a sufficiently uniform energy distribution over the transmission bandwidth for it to provide a comparable result (see Fig. 1) but the 2T pulse and the 10T composite pulse may together be sufficient. If the 10T composite pulse were used, however, either the frequency of its chrominance component would need to be an integral multiple of line frequency (see the footnote on page 3), or the control circuitry would need to be much more complicated. It is interesting to note here that the equaliser fails to correct the 1 dB/MHz 'bass cut' at frequencies below about 1 MHz, for both the sine-squared and the (sin x)/x test pulses (see Fig. 6(b)). This is because ten sections are insufficient to provide adequate correction for a transmission distortion of this type at frequencies less than 1 MHz.

In order to equalise the channel transfer characteristics shown in Fig. 6, about 50 optimisation loops were required. It is considered that this would be typical



(a) *(b)*

Fig. 6 - Effect of pulse shape on performance of 10-section time-domain equaliser

- • - • - Transmission channel characteristic ——— Overall response, equalised using 2T pulse - - - Overall response, equalised using (sin x)/x pulse

for most transmission-channel distortions. At the rate of one loop per field, the optimisation would be complete in about one second. This is relatively fast, and if noise were found to affect the sampling accuracy, it would be feasible to average over several samples and to complete the optimisation in a proportionately longer time. Again, the magnitude of the changes made per loop could be made to depend upon the magnitude of the errors, whereupon the optimisation time could be reduced. Thus it is evident that optimisation time would present no problem.

To estimate the timing accuracy required for sampling, a four-section equaliser was considered and the epoch of an undistorted test pulse was delayed, relative to the instants of sampling, by 10 ns, 20 ns and 30 ns. The resulting performance of the equaliser for 10 ns delay is shown in Fig. 7, from which it is evident that the performance is quite inadequate when using either a sine-squared or a (sin x)/x test pulse. These results confirm Arnon's suggestion that a timing accuracy of the order of 1 ns is required. It would be technically feasible to achieve this order of timing accuracy by timing the sampling process with reference to the colour bursts but, because of the non-integral relationship between the line frequency and the frequency of the colour subcarrier[10], rather complicated circuitry would be required. A similar order of accuracy would be required for the delays between the taps of the equaliser and also, of course, for the timing of the test signal (or signals), relative to the colour bursts, at the point of origin.

4. Conclusions

It is considered desirable that the great majority of links should continue to be individually equalised in order to maintain reasonable signal levels at all points in the programme chains. Experience has shown that a fixed passive equaliser is one of the most reliable parts of the chain and thus, although it would now be technically feasible to replace the fixed passive equalisers by automatic equalisers, this is not considered advisable for reasons of reliability.

Nevertheless it has been found that, despite routine adjustments, significant impairments occur over long cascades of links and it is clear that the service could be improved if reasonably reliable automatic equalisers of the type which correct residual distortions continuously throughout the programme were added at suitable points in the chain. The number of points at which such equalisers should be added would depend upon their reliability but the potential benefit to the service is great enough for this aspect to warrant further study.

Such automatic equalisers would require test signals which form part of the video programme waveform. It is highly desirable for them to be the current I.T.S. because they have become so very firmly established for other purposes and it would not be possible to add further test signals without detriment to other services that are likely to be considered more important.

In principle, either time-domain or frequency-domain equalisers could be used for this purpose but frequency-domain equalisers are recommended because not only are they better-suited to the current I.T.S. but also they are likely to be less affected by the presence of non-linear distortion. Such equalisers are now being developed for this application. Their performance is good and is unaffected by the presence of normally-accepted amounts of noise or non-linear distortion.

It is therefore recommended that automatic equalisers of the latter type should be introduced on a trial basis at suitable points in the programme chain so that the overall improvement to the service, as a function of their reliability, may be assessed.

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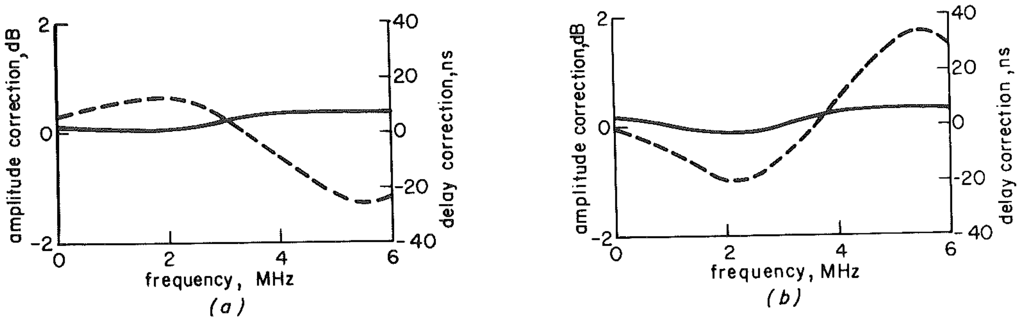

Fig. 7 - Corrections for 10 ns timing error, as made by 4-section time-domain equaliser

——— Amplitude correction - - - - - Delay correction

(a) Using 2T pulse (b) Using (sin x)/x pulse

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